

Effect of Foliar Spraying with Nano-Zinc and Addition of Organic Fertilizer and Humic Acid on the Growth and Yield of Broccoli

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ABSTRACT

Broccoli (*Brassica oleracea* var. *italica*) is a nutrient-demanding vegetable crop whose growth and productivity are strongly influenced by soil fertility and nutrient availability. This field experiment was conducted in Babylon Governorate, Iraq, during the 2025-2026 growing season to evaluate the individual and combined effects of foliar-applied nano-zinc, organic manure, and humic acid on growth and yield traits of broccoli. The experiment was arranged as a factorial trial in a randomized complete block design with three replications. Treatments included three nano-zinc concentrations (0, 1.5, and 3 g L⁻¹), three organic-manure treatments (no manure, cattle manure at 20 t ha⁻¹, and sheep manure at 20 t ha⁻¹), and three humic-acid rates (0, 10, and 20 L ha⁻¹). The highest treatment levels significantly improved plant height, leaf number, main head diameter, and total head yield. The triple interaction Z2O2H2 recorded the highest plant height (79.67 cm), leaf number (28.87 leaves plant⁻¹), main head diameter (26.33 cm), and total yield (29.87 Mg ha⁻¹), compared with the untreated control Z0O0H0, which recorded 42.33 cm, 16.33 leaves plant⁻¹, 13.33 cm, and 12.60 Mg ha⁻¹, respectively. These results indicate that integrating foliar nano-zinc at 3 g L⁻¹ with sheep manure at 20 t ha⁻¹ and humic acid at 20 L ha⁻¹ is an effective fertilization strategy for improving broccoli growth and productivity under the conditions of the study.

Keywords: Broccoli ; Nano ;Zinc; Organic fertilizer; Humic acid

1. Introduction

Broccoli depletes soil nutrients because of its high consumption during growth. Consequently, foliar feeding is an effective strategy for supplying this plant's nutritional needs due to its speed and efficiency in nutrient transport. This leads to better growth and higher yields, in both quantity and quality, while bypassing the soil-related challenges of nutrients (Witter and Lansing, 2005). The foliar feeding system is a necessary system due to its rapid nutrient delivery to the plant via its leaves. Nutrient uptake through the roots requires a longer time compared with direct application to the leaves. This change is then mirrored in the plant's

physiological and biochemical functions, quickly benefiting its growth and yield (Stojanova et al., 2016). Organic matter, whether from plant or animal residues, plays an important role in determining the physical, chemical, and biological properties of soil. These materials directly improve soil structure, increase the stability of soil aggregates, and increase the soil's capacity to retain water. They are also a source of essential nutrients for plant nutrition (Abdul-Hamza, 2010). Their biological effect is centered on the microbial biomass, which produces the enzymes necessary for plant growth and production (Scotti et al., 2015). Adding organic matter to soil has several benefits: it decreases salinity, holds more water, makes nutrients easier for plants to access, and ultimately leads to better plant growth and yield (Zribi et al., 2011; Alkarawi and Hasan, 2021). Though plants need little zinc compared to macronutrients, it's essential for their life cycle. Zinc is involved in numerous biological functions in plants, including their enzymatic systems, oxidation-reduction reactions, sugar metabolism, and energy production for life processes. Zinc also plays an important role in starch formation and in the synthesis of amino acid tryptophan, which is a source of IAA. Zinc plays a role in carbonic anhydrase, the enzyme responsible for the breakdown of carbonic acid into carbon dioxide and water (Alkarawi et al., 2024; Alkarawi, 2025). Soil fertility faces a serious threat due to decreased organic matter and humic acid, according to recent research. Humic acid's high cation exchange capacity (CEC), oxygen and nutrient content, and superior water retention capabilities are the reasons for this. For this reason, humic acid has become highly valuable for improving soil fertility, plant nutrition, and plant growth for long periods, extending to several years. Humic-acid fertilizers excel at holding onto insoluble metal ions, oxides, and hydroxides, gradually providing them to plants. Humic-acid fertilizers are recognized for their threefold, interconnected efficacy because of these characteristics, offering significant physical, chemical, and biological advantages (Stevenson, 1994; Liu et al., 2025). This study focuses on how spraying broccoli leaves with nano-zinc impacts their growth and yield. It investigates the effect of organic fertilizer on boosting crop production.

2. Material and methods

2.1 Experiment:

A field experiment was conducted in Babylon Governorate, Iraq, during the 2025-2026 growing season, within The coordinates 32°47'07.4"N 44°25'33.6"E with an elevation of 31 m above sea level, to study the effect of foliar spraying with nano-zinc and the addition of organic fertilizer and humic acid on some soil properties.

As a factorial experiment with a randomized complete block design (RCBD) and three replications, the research involved 27 experimental units per replication. The study included three factors. Nano-zinc was the first factor considered, with treatments of 0, 1.5, and 3 g L⁻¹. Organic fertilizer was the second factor, tested in three ways: no organic fertilizer, 20 t ha⁻¹ of cattle manure, and 20 t ha⁻¹ of sheep manure. The third factor was humic acid at three levels: 0, 10, and 20 L ha⁻¹, respectively. Three blocks made up the field, each separated by 1 m. There were 27 experimental units in each block. The area of each experimental unit was 6 m², with dimensions of 2 x 3 m, and a distance of 50 cm was left between experimental units. Each experimental unit was also divided into three rows. The distance between rows was 75 cm, and the distance between plants was 40 cm. A drip irrigation system was used, with one emitter for each plant. Agricultural services were consistently applied across all experimental treatments. Before planting, five random soil samples were taken from the field and mixed to create a representative composite. The soil was air-dried after plant residue removal, then pulverized with a wooden hammer, passed through a 2-mm sieve, and thoroughly mixed for

uniformity. Chemical and physical analyses of the soil were performed using samples from it, as detailed in Table 1.

Table 1. Chemical and physical properties of the soil before planting

Soil properties		Value	Units of measurement
Soil reaction (pH)		7.8	----
Electrical conductivity (EC)		.24	dS m ⁻¹
Cation exchange capacity (CEC)		22.4	cmolc kg ⁻¹ soil
Soil Organic Matter (SOM)		8.0	g kg ⁻¹
Available N		28.67	mg kg ⁻¹ soil
Available P		8.46	
Available K		121.55	
Soil separates	Sand	325.0	g kg ⁻¹ soil
	Clay	295.8	
	Silt	379.2	
Soil texture			Clay loam

2.2. Experimental measurement:

Five plants were chosen from each experimental unit for measurement, according to this procedure:

1. Number of leaves (leaves plant⁻¹): At the stage of floral head maturity, the count of fully developed leaves was recorded for each plant within the experimental units.

2. Plant height (cm): The height of plants was recorded with a metric tape measure, from the soil-contacting stem base to the uppermost leaf on the chosen plant within the experimental unit.

3. Leaf area (cm² plant⁻¹): We calculated the leaf area for one plant per experimental unit with the equation: LA = Length x Width x 0.66.

4. Main head diameter (cm): Five mature main floral heads had their diameters measured using a metric tape measure around their widest circumference. The following equation was used to determine the diameter: head diameter (cm) = circumference / 3.14.

5. Total yield (Mg ha⁻¹): To determine the experimental unit's yield, we used the following equation for total yield: total yield (Mg ha⁻¹) = yield of the experimental unit (Mg) / area of the experimental unit (m²) x 10000.

2.3. Statistical Analysis:

Statistical analysis of the data was performed with SPSS, adhering to the randomized complete block design (RCBD). Means were compared using ANOVA (Gamst et al., 2008), and the least significant difference (LSD) at the 0.05 significance level was utilized to establish any distinctions between them.

Results

Plant height (cm)

The average height of broccoli plants was significantly affected by the studied factors, as illustrated in Table 2. Compared to the control treatment Z0 (61.59 cm mean), the foliar nano-zinc treatment Z2 was superior, achieving the highest mean of 71.44 cm, with a significant increase of 15.99%. The O2 organic fertilizer treatment also outperformed, achieving the highest mean of 74.48 cm, while the O0 control treatment yielded the lowest mean of 55.59 cm, with a significant increase of 33.98%. Additionally, the humic acid treatment H2 proved

superior, yielding the highest mean of 70.15 cm, whereas the control treatment H₀ resulted in the lowest mean of 60.00 cm, with an increase of 16.91%. The findings also indicated substantial variations in every two-way interaction. A two-way interaction between foliar nano-zinc fertilizer and organic fertilizer addition (Z₂O₂) yielded the best results, achieving a mean of 78.11 cm, which was higher than the control, which gave the lowest mean of 50.78 cm, with an increase of 53.82%.

Table 2. Effect of nano-zinc spraying and addition of organic fertilizer and humic acid on average plant height (cm)

Nano-zinc	Organic fertilizer	Humic acid			Mean
		H ₀	H ₁	H ₂	
Z ₀	O ₀	42.33	51.33	58.67	50.78
	O ₁	57.33	63.00	68.00	62.78
	O ₂	67.33	71.33	75.00	71.22
Z ₁	O ₀	49.00	52.67	59.00	53.56
	O ₁	57.67	64.67	68.33	63.56
	O ₂	69.33	76.33	76.67	74.11
Z ₂	O ₀	51.67	66.67	69.00	62.44
	O ₁	69.00	75.33	77.00	73.78
	O ₂	76.33	78.33	79.67	78.11
LSD 0.05		2.73			1.57
Nano-zinc x humic acid					Mean
Z ₀		55.67	61.89	67.22	61.59
Z ₁		58.67	64.56	68.00	63.74
Z ₂		65.67	73.44	75.22	71.44
LSD 0.05		1.57			0.91
Organic fertilizer x humic acid					Mean
O ₀		47.67	56.89	62.22	55.59
O ₁		61.33	67.67	71.11	66.70
O ₂		71.00	75.33	77.11	74.48
LSD 0.05		1.57			0.91
Mean		60.00	66.63	70.15	
LSD 0.05		0.91			

The two-way interaction between foliar application of nano-zinc fertilizer and humic acid addition, Z₂H₂, gave the highest mean of 75.22 cm compared with the control, which resulted in the lowest mean of 55.67 cm, showing a 35.11% increase. The O₂H₂ treatment, combining organic fertilizer and humic acid, yielded the best results, showing a mean of 77.11 cm. This was significantly higher than the O₀H₀ treatment, which had the lowest mean of 47.67 cm, representing a 61.75% increase. Regarding the three-way interaction, treatment Z₂O₂H₂ outperformed others, yielding the highest mean of 79.67 cm. In contrast, the control treatment had the lowest mean of 42.33 cm, representing an 88.21% increase.

Number of leaves (leaves plant⁻¹)

The average leaf count is significantly affected by the factors examined, as illustrated in Table 3. Compared to the control (Z₀), which averaged 20.26 leaves per plant⁻¹, the foliar nano-zinc treatment Z₂ was more effective, resulting in the highest average of 24.37 leaves per plant⁻¹, with a significant increase of 20.28%.

Table 3. Effect of nano-zinc spraying and addition of organic fertilizer and humic acid on the average number of leaves (leaves plant⁻¹)

Nano-zinc	Organic fertilizer	Humic acid			Mean
		H ₀	H ₁	H ₂	
Z ₀	O ₀	16.33	16.67	18.33	17.11
	O ₁	18.00	19.00	22.00	19.67
	O ₂	18.67	26.33	27.00	24.00
Z ₁	O ₀	17.00	24.00	24.43	21.81
	O ₁	20.33	24.33	25.43	23.37
	O ₂	21.00	27.00	27.10	25.03
Z ₂	O ₀	20.00	25.00	25.10	23.37
	O ₁	20.33	26.00	26.33	24.22
	O ₂	20.33	27.33	28.87	25.51
LSD 0.05		2.47			1.42
Nano-zinc x humic acid					Mean
Z ₀		17.67	20.67	22.44	20.26
Z ₁		19.44	25.11	25.66	23.40
Z ₂		20.22	26.11	26.77	24.37
LSD 0.05		1.42			0.82
Organic fertilizer x humic acid					Mean
O ₀		17.78	21.89	22.62	20.76
O ₁		19.56	23.11	24.59	22.42
O ₂		20.00	26.89	27.66	24.85
LSD 0.05		1.42			0.82
Mean		19.11	23.96	24.96	
LSD 0.05		0.82			

Treatment O₂, an organic fertilizer, also outperformed the others, yielding the highest average of 24.85 leaves per plant. In contrast, the control treatment O₀ resulted in the lowest average of 20.76 leaves per plant, representing a significant 19.70% increase. The humic acid treatment H₂ was also superior and gave the highest mean of 24.96 leaves plant⁻¹ compared with the control treatment H₀, which gave the lowest mean of 19.11 leaves plant⁻¹, with an increase of 30.61%. In addition, the findings revealed substantial differences across all two-way interactions.

Z2O2, a combination of foliar nano-zinc fertilizer and organic fertilizer, outperformed the control (Z0O0), resulting in an average of 25.51 leaves per plant, a 49.09% increase over the control's average of 17.11 leaves per plant. Compared to Z0H0, which had the lowest average of 17.67 leaves per plant⁻¹, the combined foliar application of nano-zinc fertilizer and humic acid (Z2H2) resulted in the highest average of 26.77 leaves per plant⁻¹, with an increase of 51.49%. When considering how organic fertilizer and humic acid interact, the O2H2 combination proved best, yielding 27.66 leaves plant⁻¹, significantly more than the O0H0 combination's 17.78 leaves plant⁻¹, with an increase of 55.56%. The three-way interaction showed that Z2O2H2 was the superior treatment, yielding a mean of 28.87 leaves plant⁻¹. Compared to the control treatment Z0O0H0, which resulted in the lowest average of 16.33 leaves per plant, there was a 76.79% increase.

Main head diameter (cm)

The average main head diameter exhibits significant differences in response to the factors analyzed, as depicted in Table 4. The foliar nano-zinc treatment Z2 was the best, yielding a mean of 22.37 cm. A significant 14.60% increase was observed compared to the control treatment Z0, which had the lowest mean of 19.52 cm.

The organic fertilizer O2 outperformed the control (O0), yielding the highest average height of 23.48 cm, a 34.63% increase over the control's 17.44 cm. The humic acid treatment H2 demonstrated superiority, achieving the highest mean of 22.00 cm. This contrasts with the control treatment H0, which yielded the lowest mean of 19.74 cm, representing an 11.44% increase. The findings also revealed notable disparities in every two-way interaction. Compared to the control (Z0O0), the dual application of foliar nano-zinc and organic fertilizer (Z2O2) was more effective, resulting in the greatest average height of 24.78 cm, which gave the lowest mean of 15.22 cm, with an increase of 62.81%. The two-way effect of Z2H2 comes from its foliar nano-zinc fertilizer application and humic acid addition, giving the highest mean of 23.33 cm compared with Z0H0, which gave the lowest mean of 18.22 cm, with an increase of 28.04%. A two-way interaction analysis showed that treatment O2H2, with both organic fertilizer and humic acid, resulted in the highest average measurement of 24.33 cm, compared with O0H0, which gave the lowest mean of 15.78 cm, with an increase of 54.18%. As for the three-way interaction, treatment Z2O2H2 was superior and gave the highest mean of 26.33 cm compared with the control treatment Z0O0H0, which gave the lowest mean of 13.33 cm, with an increase of 97.52%.

Table 4. Effect of nano-zinc spraying and addition of organic fertilizer and humic acid on head diameter (cm)

Nano-zinc	Organic fertilizer	Humic acid			Mean
		H ₀	H ₁	H ₂	
Z ₀	O ₀	13.33	14.67	17.67	15.22
	O ₁	20.33	19.00	22.00	20.44
	O ₂	21.00	23.00	24.67	22.89
Z ₁	O ₀	15.00	15.33	19.00	16.44
	O ₁	21.67	20.00	22.67	21.44
	O ₂	22.33	24.00	22.00	22.78
Z ₂	O ₀	19.00	22.00	21.00	20.67

Nano-zinc	Organic fertilizer	Humic acid			Mean
	O ₁	21.67	20.67	22.67	21.67
	O ₂	23.33	24.67	26.33	24.78
LSD 0.05		2.03			1.17
Nano-zinc x humic acid					Mean
Z ₀		18.22	18.89	21.44	19.52
Z ₁		19.67	19.78	21.22	20.22
Z ₂		21.33	22.44	23.33	22.37
LSD 0.05		NS			0.68
Organic fertilizer x humic acid					Mean
O ₀		15.78	17.33	19.22	17.44
O ₁		21.22	19.89	22.44	21.19
O ₂		22.22	23.89	24.33	23.48
LSD 0.05		1.17			0.68
Mean		19.74	20.37	22.00	
LSD 0.05		0.68			

Total yield of main heads (Mg ha⁻¹)

According to Table 5, the factors examined had a significant impact on the average total yield of main heads. Z₂, the foliar nano-zinc treatment, outperformed the control (Z₀) with the highest mean yield of 23.86 Mg ha⁻¹. A significant 8.50% increase was observed, with the lowest mean recorded at 21.99 Mg ha⁻¹. The organic fertilizer treatment O₂ was also superior and gave the highest mean of 26.22 Mg ha⁻¹ compared with the control treatment O₀, which gave the lowest mean of 17.94 Mg ha⁻¹, with a significant increase of 46.15%. The humic acid treatment H₂ was also superior and gave the highest mean of 26.78 Mg ha⁻¹ compared with the control treatment H₀, which gave the lowest mean of 17.83 Mg ha⁻¹, with an increase of 50.19%. The outcomes also revealed notable disparities in every two-way interaction. A mean yield of 26.91 Mg ha⁻¹ was most effectively achieved with the two-way application of nano-zinc and organic fertilizers (Z₂O₂), surpassing the control (Z₀O₀), which resulted in the lowest average of 16.47 Mg ha⁻¹, showing a 63.38% rise. The highest mean yield of 27.05 Mg ha⁻¹ was achieved with Z₂H₂, which involved a two-way interaction between nano-zinc fertilizer applied to leaves and the addition of humic acid, compared with Z₀H₀, which gave the lowest mean of 17.13 Mg ha⁻¹, with an increase of 57.91%. Regarding the two-way interaction between organic fertilizer addition and humic acid addition, treatment O₂H₂ was superior and gave the highest mean of 29.53 Mg ha⁻¹ compared with O₀H₀, which gave the lowest mean of 13.31 Mg ha⁻¹, with an increase of 121.8%. Regarding the three-way interaction, Z₂O₂H₂ treatment excelled, yielding the highest mean of 29.87 Mg ha⁻¹, compared with the control treatment Z₀O₀H₀, which gave the lowest mean of 12.60 Mg ha⁻¹, with an increase of 137.06%.

Table 5. Effect of nano-zinc spraying and addition of organic fertilizer and humic acid on average total yield of main heads (Mg ha⁻¹)

Nano-zinc	Organic fertilizer	Humic acid			Mean
		H ₀	H ₁	H ₂	

Nano-zinc	Organic fertilizer	Humic acid			Mean
Z ₀	O ₀	12.60	15.05	21.77	16.47
	O ₁	18.98	25.30	27.97	24.08
	O ₂	19.80	27.40	29.03	25.41
Z ₁	O ₀	13.33	16.38	23.65	17.79
	O ₁	19.65	26.10	27.73	24.50
	O ₂	20.37	28.93	29.70	26.33
Z ₂	O ₀	14.00	21.67	22.98	19.55
	O ₁	20.66	26.43	28.30	25.13
	O ₂	21.10	29.77	29.87	26.91
LSD 0.05		1.68			0.05
Nano-zinc x humic acid					Mean
Z ₀		17.13	22.58	26.26	21.99
Z ₁		17.78	23.81	27.03	22.87
Z ₂		18.59	25.96	27.05	23.86
LSD 0.05		0.97			0.56
Organic fertilizer x humic acid					Mean
O ₀		13.31	17.70	22.80	17.94
O ₁		19.76	25.94	28.00	24.57
O ₂		20.42	28.70	29.53	26.22
LSD 0.05		0.97			0.56
Mean		17.83	24.11	26.78	
LSD 0.05		0.56			

Discussion

Data from Tables 2, 3, 4, and 5 demonstrate a notable enhancement in broccoli growth and yield with organic fertilizer. We observed greater plant height and leaf numbers, along with better productive features, as a result. This improvement likely stems from organic fertilizers' ability to boost organic matter, refine soil structure, and elevate cation exchange capacity (Demir et al., 2022). The decomposition of organic matter also releases nutrients gradually, such as nitrogen, phosphorus, and potassium, thereby improving the mineral nutrition of the plant and increasing the efficiency of vegetative growth and leaf formation. This is reflected in increased chlorophyll content and improved photosynthetic efficiency, and consequently increased accumulation of carbohydrates that are translocated to the floral head, leading to increased head size and weight and consequently higher total yield (Lal, 2020). Compared to cattle manure, sheep manure is superior because of its greater nutrient density and less nutrient loss as it breaks down, which leads to faster and more efficient release of macro- and micronutrients and therefore increases their availability for absorption by the plant. Conversely, cattle manure has more fiber and moisture, leading to slower decomposition and delayed nutrient release. Humic acid addition resulted in a notable improvement in broccoli growth and yield characteristics, according to the current study's

results. The improvement of soil's physical and chemical properties by humic substances is likely the reason for this (Ampong et al., 2022; Sardar et al., 2022). In addition, humic acid possesses active functional groups, such as carboxyl and hydroxyl groups, which give it high chelating ability, reducing nutrient leaching and increasing the availability of phosphorus and micronutrients by preventing their fixation in the soil. Moreover, humic acid acts as a biostimulant for microorganisms, accelerating the carbon and nitrogen cycles and contributing to improved uptake of mineral elements by the plant (Bezuglova and Klimenko, 2022). The findings align with Hawall et al. (2018) and Ibrahim et al. (2024).

Conclusion

We conclude from the results of the study that enhanced soil characteristics and nutrient availability in the soil led to a greater accumulation of elements in the leaves. This leads to better plant growth and yields, confirming the strong link between soil fertility, plant nutrition, and broccoli production.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

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